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THE ROLE OF SEWAGE LAGOONS AT CORPS OF ENGINEERS RECREATION AREAS

by

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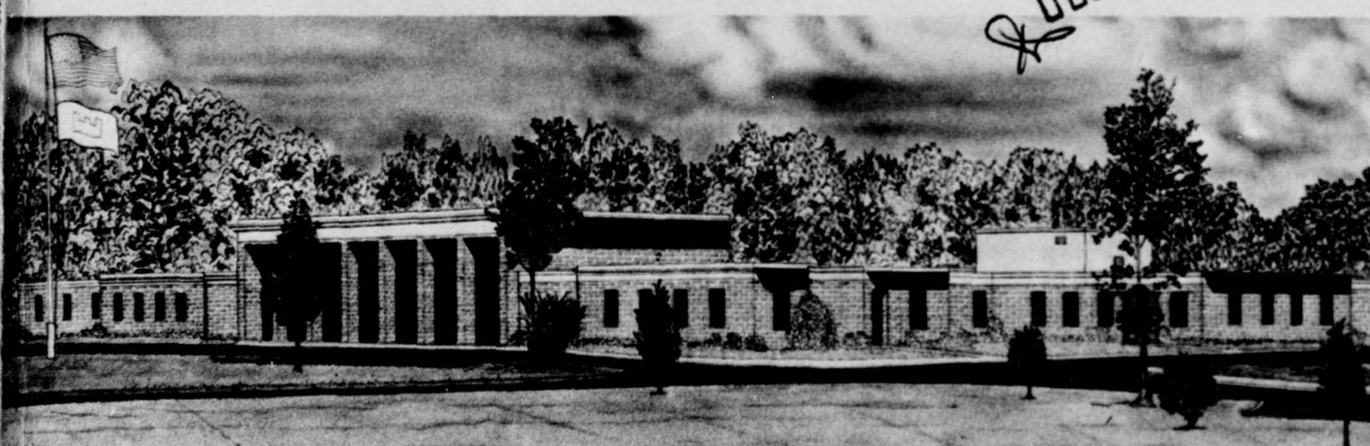

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This survey report was prepared to assess the role of Corps of Engineers recreation area sewage lagoons in light of recent technology and current and future Corps problems and needs. A review of the literature was conducted to identify design, operation, and upgrading methods that may be applicable to the special loading problems and other circumstances characteristic of recreation area lagoons. Concurrently, a survey was conducted to establish the geographic distribution and the design and performance successes and failures of the more

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than 200 Corps recreation area lagoons nationwide. Steps are recommended for improving lagoon waste treatment at recreation areas based on current knowledge, and areas of needed research are identified.

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PREFACE

The study herein was funded by the Office, Chief of Engineers, U. S. Army, from Civil Works Appropriation 96X3121, General Investigation--Research and Development.

The literature research and field visits were conducted by CPT Terry D. Hand, CE, and Mr. Randall R. Williams both of the Environmental Effects Laboratory (EEL), U. S. Army Engineer Waterways Experiment Station (WES). CPT Hand was principal author with contributions from Mr. Williams. The study was conducted under the direct supervision of Mr. N. R. Francingues, Chief, Treatment Processes Research Branch, EEL, and Mr. A. J. Green, Chief, Environmental Engineering Division, EEL, and under the general supervision of Dr. John Harrison, Chief, EEL.

Director of WES during this study was COL John L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

The U. S. customary units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimetres
feet	0.3048	metres
acres	4046.856	square metres
cubic yards	0.7645549	cubic metres
gallons	0.003785412	cubic metres
pounds (mass)	0.4535924	kilograms
horsepower	745.6999	watts

THE ROLE OF SEWAGE LAGOONS AT CORPS OF ENGINEERS RECREATION AREAS

PART I: INTRODUCTION

Background

1. Sewage lagoons or waste stabilization ponds--the terms may be used interchangeably--have risen rapidly in popularity since the end of World War II. It is estimated that between 1945 and 1970 the number of lagoons treating municipal wastewater in the United States increased a hundredfold, from less that 50 to nearly 5000.[1]

2. The factors which favor the lagoon as a treatment alternative are: low construction cost, low operation and maintenance costs, simplicity of operation, and relative insensitivity to loading fluctuations. Principal arguments against the use of lagoons include: inconsistent or unpredictable (frequently poor) effluent quality, odors and other aesthetic objections, and large land area requirement.

3. The use of lagoons by the Corps of Engineers at Civil Works projects has been a comparatively recent development. Most lagoon construction has been accomplished during the past 5 to 10 years accompanying the extensive expansion and improvement of public recreational facilities by the Corps during roughly the same period. Other agencies, notably the U. S. Forest Service and various State recreation and highway departments, have used lagoons in conjunction with seasonal outdoor recreation facilities and rest areas for many years.

4. Decisions by planners in Corps field offices to specify lagoons instead of alternative methods and the designs and schemes actually implemented have been based on such considerations as climate, soil, topography, waste characteristics, and State and local regulations and politics. The extent to which lagoons have met treatment objectives and applicable standards varies from region to region and project to project and depends on many factors, some controllable and some not.

Purpose

5. It is the intent of this study to assess the role that sewage lagoons have played and may be expected to play in the future at Corps recreation areas and to evaluate and interpret the success or failure of these lagoons. The study was conducted based on the following specific objectives:

- a. To evaluate the present state of lagoon technology as it applies to those problems unique to Corps facilities.
- b. To identify problem areas in Corps-operated lagoons and offer design and operational suggestions that could be implemented immediately where applicable.
- c. To recommend areas of needed research, the results of which would materially improve the effectiveness of the Corps' present and future lagoon systems and additionally be of use to various other Federal and State agencies using lagoons for similar, if not identical, purposes.

Scope

6. To accomplish these objectives, an extensive survey of the literature on lagoons was conducted that included a determination of on-going and future lagoon research by various agencies and groups. Additionally, a series of visits to Corps field offices, project sites, and lagoon sites was made to acquire all available information on Corps-built or operated lagoons.

7. Together the literature search and field visits have yielded an enormous amount of information on the theory, design, and operation of lagoons as well as considerable performance and monitoring data. In this report the mass of data will be consolidated to the extent required to provide a summary relevant to Corps problems and interests.

8. This study is necessarily limited to consideration of lagoons principally serving the recreation facilities at Civil Works projects, as this is where the Corps' wastewater problems are unique. Although lagoon treatment facilities are constructed and, in some cases, operated by the Corps at military installations, these fall largely into the category of municipal systems. In comparison, recreation area lagoons

offer a completely different set of loading and operating circumstances. Municipal lagoons (continuous, year-round flows) have been extensively discussed in the literature, and information pertaining to them is included here only as it applies to the situation found at recreation areas.

9. Additional information on the subject of sewage lagoons can be found in the sources listed in the Bibliography following the References.

Nature of the Problem

10. The most prominent aspect of wastewater systems at recreation areas, which sets them apart from conventional municipal systems, is the extreme variability of the flows produced. A typical recreation area will produce virtually an entire year's wastewater flow between April and October, the outdoor recreation season, with 80 to 90 percent of that flow coming between Memorial Day and Labor Day. Superimposed on this seasonal pattern is a distinct weekly pattern which finds approximately 80 percent of a typical week's flow occurring during the 48-hr period from 6:00 p.m. Friday to 6:00 p.m. Sunday. These peaks are even more pronounced during major holiday weekends.*

11. An additional aspect of most recreation area wastewaters which causes the weekly flow fluctuations to have an even greater impact on the treatment system is the fact that the average flows are usually relatively small. In a sewerage system generally, as the average flow becomes smaller, the peak flow becomes an ever larger multiple of the average flow.

12. These problems have been recognized for several years since the widespread introduction of waterborne sanitary facilities at remote outdoor recreation sites. Any treatment system, to be effective, must be capable of handling widely fluctuating hydraulic and organic loads which flow for only about 6 months of the year.

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* Unpublished results of study conducted at Deer Creek Reservoir, Ohio, by the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., 1976.

13. Three types of treatment systems have seen widespread recreation area use to date: septic tank-drainfield systems, package activated sludge plants (extended aeration primarily), and lagoons or stabilization ponds. None has proven to be a panacea, yet each has some merit and has provided effective treatment under certain circumstances. It is believed that all three types of systems will continue to have useful application at recreation areas. The ultimate selection of a particular treatment alternative must, of course, rely on local conditions and sound engineering judgment.

14. In addition to the small, highly variable, and seasonal flows that are more or less unique to recreation area wastewaters, some other factors, applicable at Corps projects and having an important influence on the treatment process to be selected, include:

a. Availability and capability of qualified operators.

b. Availability and suitability of land and soil characteristics.

c. Relative cost of alternatives (construction, operation, and maintenance).

d. Climatic conditions.

e. Effluent standards, discharge restrictions, receiving water quality, and other environmental/health/legal factors.

f. Attitudes of Federal, State, and local authorities.

g. Capabilities, experience, and tradition among Corps field office engineering personnel.

15. These are the primary issues against which lagoons, or any other treatment system, must be evaluated. Recreation areas, as seen, offer an altogether different type of wastewater management challenge from most municipal and industrial sources. However, in too many cases there has been a tendency by Corps personnel and others to design recreation area waste treatment systems based on essentially municipal criteria. In defense of Corps designers, however, it must be said that, of those interviewed, each listed a valid set of criteria for determining water usage, wastewater production, and wastewater characteristics for the various kinds of facilities provided at Corps projects as the

most pressing need in the field of recreation area sanitary design. (This problem is also currently under study by the Environmental Effects Laboratory (EEL), WES.)

PART II: DISCHARGE STANDARDS

16. The measure of operational success in a waste treatment process is usually given in terms of the percent removal of a particular undesirable constituent, such as biochemical oxygen demand (BOD), suspended solids (SS), nitrogen, phosphorus, and coliform bacteria, or else in terms of the concentration of these constituents in the effluent.

17. The legal and authoritative source for effluent standards today are the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500). These provide that by 1 July 1977 all publicly owned point discharges will have achieved secondary treatment. The following tabulation shows the effluent standards for secondary treatment as defined by the Environmental Protection Agency (EPA).[2]

Parameter	30-Day Mean	7-Day Mean
BOD_5 (arithmetic mean)	30 mg/ℓ or 85 percent removal	45 mg/ℓ
Suspended solids (arithmetic mean)	30 mg/ℓ or 85 percent removal	45 mg/ℓ
Fecal coliform bacteria (geometric mean)	200 per 100 mℓ	400 per 100 mℓ
pH of effluent	Between 6.0 and 9.0	Between 6.0 and 9.0

18. These standards fully apply to discharging lagoons, which are generally regarded as secondary treatment facilities. They are usually the limitations found in the National Pollutant Discharge Elimination System (NPDES) permits for Corps lagoon installations unless the receiving water is of a quality and flow requiring a more stringent effluent limitation.

19. A recent proposed amendment to PL 92-500, published in the Federal Register of 2 September 1976,[3] may allow variances in the SS limitation to be granted for certain lagoons. The proposed change would allow the EPA Regional Administrator or State authority, where applicable, to increase the allowable SS in lagoon effluents to a level deemed

"...achievable by best waste stabilization pond technology..." in the state or region where the pond is located. To qualify for a variance, a lagoon would have to meet the following requirements: (a) be the sole process used for secondary treatment; (b) have a maximum design capacity of 1 mgd* or less; (c) have demonstrated an inability to meet the unamended SS limitation. It would further have to be a properly designed and operated and publicly owned treatment facility. The BOD limitations would remain unchanged.

20. The proposed amendment is an indication that the EPA has recognized: (a) that small municipal lagoons are the only practical method of secondary treatment affordable by hundreds of communities and that they are here in great numbers and here to stay and (b) that lagoons cannot by themselves consistently achieve the 30 mg/ℓ SS limitation due to algae in their effluents.

21. All of the Corps' lagoons are in the less than 1-mgd category and, except for those ponds which follow package activated sludge plants, all would presumably be considered under the provisions of the amendment to the regulations. Although the proposed amendment will take some of the immediate pressure off in regard to the implementation of an expensive algae removal scheme, it should not be construed as completely exempting small lagoons from performance in this area. On the contrary, SS limits will be set in accordance with best pond technology. Moreover, on water-quality-limited streams, lagoon effluents must meet the standards imposed by the stream regardless of lagoon size or regulation amendments.

22. Thus, there is ample reason to continue efforts to improve lagoon performance within the context of the 1977 Federal standards alone. Beyond 1977 are the 1983 standards which will require removal of nitrogen and phosphorus, already required in some locations by State regulation, and the 1985 goal of zero pollutant discharge nationwide.

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* A table of factors for converting U. S. customary units of measurement to metric (SI) can be found on page 4.

PART III: LAGOONS: A LITERATURE REVIEW

Summary of Lagoon Technology

Introduction

23. Lagoons of all types have been the subject of intense study during the past 10 years. The continuing heightened interest may be the result of increased environmental awareness in general but is more likely to have originated with the Federal Water Quality Act of 1965 and the accompanying requirement that small and medium-sized towns start treating their sewage. Lagoons were recognized early as an inexpensive way to provide a reasonable degree of treatment. Today, as acknowledged secondary treatment facilities, lagoons are more important than ever, particularly for small and remote communities with limited means. The combination of economy, simplicity, and reliability that lagoons represent has made lagoons an alternative worthy of careful consideration and extensive study.

24. Lagoon research has been directed toward every conceivable aspect of the problem: biological, hydraulic, sanitary engineering, construction, public health, and economic. The difficulty has been that each aspect itself is elusive and may have different answers depending on the regional location of the particular lagoon under study. Consequently, there are few generalizations which can be valid on the nationwide scale in which the Corps operates. Each existing and anticipated Corps lagoon, then, must be evaluated not only in terms of the unique seasonal and weekly loading it receives but also in terms of local climate, topography, soil, governmental regulations, and official and unofficial attitudes. When viewed in this context, lagoons graphically bring out the importance of engineering judgment and common sense.

25. Although most recent lagoon research has been directed toward larger, continuous-flow municipal systems, many of the findings are of general interest and can be applied to Corps lagoons as well. Therefore, a selected summary is included herein. Although the basic mechanisms by which lagoons stabilize organic wastes are well understood, lagoons

seldom fit into quantitative mathematical models such as the one presented by Thirumurthi.[4] Of the three basic types of lagoons--anaerobic, facultative, and aerated--the facultative lagoon, with its bacteria-algae symbiosis, is the most biologically and chemically complex. It is also the most common type at Corps areas and elsewhere and the type with the least predictable performance.

26. The anaerobic lagoon is most effectively used with highly concentrated industrial and food processing wastes but could be used effectively in a municipal or recreation area lagoon system as the primary cell where solids are allowed to settle out and anaerobically digest. Septic tanks are actually nothing more than covered anaerobic lagoons, and they are widely used in conjunction with facultative ponds in the Corps' South Pacific Division and Southwestern Division.

27. Aerated lagoons, equipped with either surface-mechanical or diffused air systems, have become more popular in recent years. By replacing or supplementing algal photosynthesis as the oxygen source, aerators allow significant reductions in required surface area and provide greater performance predictability. The trade-off is in increased capital cost, complexity, maintenance requirements, and power costs. Highly powered (greater than about 50 hp/mg), completely mixed aerated lagoons become virtually indistinguishable from low-power, activated sludge units without sludge recycle.

Design

28. The following paragraphs on lagoon design are directed primarily toward facultative ponds. The word lagoon, unless otherwise specified, is intended to mean facultative lagoon.

29. Lagoon design has evolved since the late forties from very rough and often mistaken rules of thumb, through trial and error, common sense, and controlled experimentation, to the relatively rational, though still mostly empirical, processes in general use today.

30. Approval. Design approval is largely in the hands of State agencies,[5-8] and, besides construction details, the design parameter of primary concern is surface BOD_5 loading given in pounds/acre/day. The following tabulation gives the accepted ranges for organic surface

loading as well as depth and hydraulic detention time for the three basic types of lagoons. The higher allowable organic loads for facultative lagoons prevail in the warm, sunny climates that favor microbial and photosynthetic activity.

Type of Lagoon	Depth ft	Hydraulic Detention Time, days	Organic Loading lb BOD_5/acre/day
Anaerobic	8+	4 to 10	500 to 4,000
Facultative	2 to 6	30 to 120	20 to 75
Aerated	6 to 12	2 to 20	100 to 10,000

31. There has been much effort made toward finding the optimum lagoon design, particularly for the correct organic loading rate; however, it is the opinion of the author that there are too many uncontrollable factors influencing lagoon performance in the field to justify some of the elaborate formulas and models devised to assist in design. If a Corps designer knows the sewage characteristics and flow rates, knows the climate and weather patterns at the site and their effects on lagoon performance, and follows any of the empirical design methodologies from the literature (subject, of course, to State criteria), chances are slight that the design will be inadequate.

32. Depth. Operating depth is an arbitrary facultative pond design feature, usually specified to be maintained between 2 and 6 ft, or more commonly, 3 and 5 ft, depending on the individual State's criteria.[7,8,9] The lower limit of 2 or 3 ft is necessary to guard against emergent weed growth and to provide an insulating buffer over the anaerobic sludge layer found at the bottom of facultative ponds. (This lower depth limit is frequently violated by Corps lagoons.) However, the upper limit of 5 or 6 ft is without a valid, rational basis other than the fact that deeper ponds have higher excavation costs. From a theoretical point of view, a deeper pond may actually enhance performance. It would provide more hydraulic detention time which would allow more complete coliform die-off. It would also provide a deeper buffer for the sludge layer without reducing the size of the aerobic photosynthetic layer or preventing desirable mixing in the upper zones. The sludge would be less frequently resuspended by mixing and more

dilute when it is suspended; this should result in less frequent and less acute hydrogen sulfide (H_2S) odors. A deeper pond would provide greater storage for wet weather peak flows or complete seasonal retention without increasing surface area. Finally, a deeper pond would allow for more effective multilevel withdrawal by telescoping the vertical distribution of SS and increasing the thickness of any clear zone which may exist.

33. Multiple cells. Multiple cells have become universally accepted as a desirable design feature. Whether they should be arranged in parallel or series or both is in dispute and, like most other aspects of lagoon design, depends on local conditions and the method of operation and discharge. The most versatile arrangement is to provide for both series and parallel operation. In a survey of 31 Midwestern lagoons, Howells and Dubois[10] found that construction cost was not significantly higher when comparing multicellular systems to single cells of the same total area.

34. Flow control structures. Inlet and outlet structures have not received much attention in the literature although they can have a tremendous effect on performance. Among Corps lagoons alone there are dozens of different designs that range in effectiveness from excellent to poor. It is agreed that inlets, outlets, and intercell connecting pipes should allow the greatest possible operational flexibility for parallel or series operation or combinations thereof, depending on the number of cells in the system. Additionally, it is considered good practice to provide all pipes with gate valves.

35. Inlets should be submerged, firmly anchored, provided with a concrete splash block, and built to discharge horizontally near the pond bottom if waste is under gravity flow, or vertically upward if the waste is under pressure. Most State design standards require the inlet to be near the center of a square or round pond and at a third of the distance along the long axis in rectangular or oval ponds. Barsom,[1] in his assessment of lagoon technology, concluded that short-circuiting is the most common and most important problem in lagoons in the United States and that inlets located at or near the center is the major cause.

A better arrangement would be to place the inlet near one end of a long, narrow lagoon and the outlet at the other. Barsom has also recommended that states allow and encourage placement of baffles in the lagoon to force the contents to approach theoretical detention times. Breaking up the lagoon into three or more small series-operated cells can accomplish much the same thing. Recirculation of lagoon effluent, used successfully in Sweden,[11] will also alleviate the effects of short-circuiting.

36. Outlet structures should, but rarely do, provide for drawing effluent off at a variety of depths. (Many states specify 12 to 18 in. below the surface.) There should also be a pipe at the low water level (2 or 3 ft) and an emergency overflow pipe. It is felt by the author that research is needed in the area of inlet and outlet structures.

37. <u>Liners.</u> Whether a lagoon should be lined or not depends on such factors as water table location, permeability of soil, aquifer characteristics, and local use of groundwater.

38. Some states allow and expect up to 1/4 in. of seepage per day to be included in the design, but the trend is toward more stringent standards with smaller seepage allowances. For example, Pennsylvania, in 1972, adopted regulations requiring all new lagoons of all types to have liners that are absolutely impervious.[12] The following types of commercially available liners are listed in order of lowest to highest price.[12]

- <u>a</u>. Bentonite (clay).
- <u>b</u>. Phillips Petromat.
- <u>c</u>. Polyethylene.
- <u>d</u>. Polyvinyl Chloride (PVC)-20 mil.
- <u>e</u>. Clay-bentonite (Volclay).
- <u>f</u>. 3110 (unsupported)-20 mil.
- <u>g</u>. Chlorinated Polyethyelene (CPE) (unsupported)-21 mil.
- <u>h</u>. CPE (unsupported)-30 mil.
- <u>i</u>. Hypalon (unsupported)-30 mil.
- <u>j</u>. Butyl (unsupported)-30 mil.
- <u>k</u>. PVC (supported)-30 mil.
- <u>l</u>. Hypalon (supported)-30 mil.

m. CPE (supported)-30 mil.

n. Butyl (supported)-30 mil.

o. Ethyl Propylenediene Monomer (EPDM)-30 mil.

p. Neoprene.

39. Two frequent complaints concerning membrane type liners, besides their susceptibility to holes and tearing, is that they tend to float when water tables are high, and if sludge or raw sewage somehow becomes trapped beneath the liner it will anaerobically decay, releasing gas causing the liner to balloon.

40. In addition to membranes and commercial bentonites of various types, consideration should be given to sealing ponds with local clays, asphaltic materials, and concrete.

41. Construction details such as dike slopes and width, compaction requirements, freeboard, and the like are adequately covered by State design criteria (e.g., Ten States Standards).[8] Special attention should be given to pond location and orientation (in the open, down wind from inhabited areas, and with wind sweep along the length of the lagoon away from the outlet), erosion, and weed growth prevention on inner dike slopes.

Operation

42. Unless it is mechanically aerated or includes a chlorination step, a continuously loaded and discharging lagoon literally operates itself. Lagoons, depending on their size and number of cells, can naturally handle organic and hydraulic surges with relatively little effect on the effluent; the same surges would wash out or severely upset a mechanical/biological treatment plant of similar capacity. Moreover, lagoons are less susceptible to slugs of toxic material than comparable mechanical treatment systems. They require no power, no chemicals (except chlorine, perhaps), and little maintenance. Lagoon desirability is obvious for small towns and remote areas, such as Corps reservoirs, which do not have the resources to provide a full-time skilled treatment plant operator.

43. For most lagoon designs the type of operational effort required is simple enough for a layman to perform on a part-time basis.

Examples of lagoons requiring somewhat greater operational effort are: aerated lagoons, multicelled systems and those discharging intermittently, and lagoons followed by chlorinators, sand filters, or some other subsequent process. Lagoon maintenance is similarly simple, requiring only nonspecialized tasks (e.g., grass cutting, weed removal, dike inspection and repair, inspection of lagoon for odors and algae mats, and manual removal of the latter).

Performance

44. Lagoons have been studied extensively to determine their ability to remove BOD, SS, total and fecal coliforms, and to some extent phosphorus and nitrogen. Performance data are available that can be used to support a variety of conflicting conclusions to these and other questions, but in recent years there has been increasing concensus in the literature and awareness in regulatory agencies that continuously discharging lagoons cannot alone meet the 1977 secondary treatment standards. The problem is the presence of algal solids in the effluent.

45. Algae, an essential oxygen producing component of the lagoon biota, is an unwanted pollutant in an otherwise well-treated effluent. Not only is algae an overt form of SS that colors and may impart odors to the receiving water but it contains a high ultimate oxygen demand that is exerted in the receiving water; its 5-day BOD, though only about 20 percent of its ultimate BOD, can be up to 85 percent of the BOD_5 of the lagoon effluent.[1]

46. Lagoon performance capability is best summarized, for purposes of this report, by Table 1, which gives a qualitative rating from 1 to 4 to the ability of facultative lagoons to remove the indicated constituent. The ratings have been arrived at by digesting and consolidating performance data on hundreds of lagoons in scores of articles and reports.

47. In some northern states, namely Michigan, Wisconsin, and the Dakotas, lagoons are most often designed to store 6 months of flow and only discharge twice a year. The technique grew out of the realization that during very cold weather and extensive periods of ice cover very little biological activity takes place. The combination of low BOD

loading (20 lb/acre/day or less) and long detention times in these "controlled discharge" lagoons has resulted in effluents that approach the 1977 secondary treatment standards.[13-15] Moreover, there is no pollutant discharge at all except for a week or two during November and April. Discharges are authorized when algal concentrations in the lagoon are low and receiving stream flows are generally high. This technique has not been reported in the literature for other parts of the country where the temperature extremes are not so severe and is a subject which definitely merits further investigation.

48. In the arid and semiarid regions of the country many lagoons, particularly those that are lightly or intermittently loaded, are totally evaporative and never discharge. Some are designed this way while others, intended to be discharging lagoons, either were hydraulically overdesigned or suffer excessive seepage. At any rate, zero discharge lagoons are the ideal solution where feasible. Maintenance of an adequate water level to preclude odor problems is the biggest short-term difficulty while gradual dissolved salt buildup would be the biggest long-term problem, though there have not been any reports of pond failures due to toxic salt levels.

49. As will be discussed later the zero discharge lagoon and variations of the controlled discharge technique are currently important to the Corps and are probably the key to future Corps lagoons.

50. Other significant aspects of lagoon performance include pH, chlorination effects, and dissolved oxygen. The photosynthetic activity in the algae-laden layers, from which most effluents are drawn, produces a high pH, often above the upper limit of 9.0 set by the 1977 secondary treatment standards. At night when photosynthesis stops and mixing takes place the pH will generally drop to near 7.0 throughout the pond depth.[16]

51. Clorination has been shown to effectively disinfect algae-laden lagoon effluent when necessary, but residuals are difficult to maintain and doses must be carefully determined by laboratory experiment with the actual effluent. Further, too much chlorine breaks down algal cells and releases soluble BOD and nutrients to the water.[17]

52. Daytime lagoon effluents with high algal concentrations are usually supersaturated with dissolved oxygen, whereas nighttime effluents or those taken from below the photosynthetic layer are usually low in or devoid of oxygen.

Costs

53. Lagoon construction costs depend almost completely on the cost of excavation in the proposed locale, and per yard excavation cost depends on such factors as amount of rock, slopes, compaction effort required, and local labor prices.

54. Recognizing the variability of excavation costs but assuming a typical cost of $1.00/cu yd, a 3-acre lagoon system loaded at 20 lb BOD/acre/day would cost on the order of $30,000 to $35,000 at 1972 prices.[18] This price includes seeding, fencing, and inflow and outflow structures. This lagoon system would serve a typical municipal population of 300 people or a hydraulic load of 30,000 gal/day (gpd).

55. A typical 30,000-gpd package extended aeration plant, which would be the most likely alternative to the lagoon at a recreation site, would cost about $40,000 assembled, at 1972 prices.[18]

56. A 1959 study of stabilization ponds costs in the Midwest[10] indicates that the number of cells does not markedly affect the cost of the lagoon system.

57. Much more land is required for lagoon systems than for mechanical treatment plants, and where suitable land is expensive or scarce, lagoons lose much of their attractiveness. At Corps projects, however, there is usually adequate, suitable land already owned by the Government.

58. Operation and maintenance is the category in which lagoons excell. With extrapolation, curves provided in the EPA's "Estimating Costs and Manpower Requirements for Conventional Wastewater Treatment Facilities"[18] show that the above-mentioned 3-acre faculative lagoon system would cost approximately $1500/year to operate and maintain. A comparable figure for the 30,000-gpd package plant would be about $7000/year. Both figures are based on 1972 prices.

Recent Research

59. In lagoon research the 6 years between 1965 and 1971 were characterized by basic investigations into the mechanisms, capabilities, and demonstrated performance of lagoons in the field. Since 1972, on the other hand, research has been largely devoted to developing ways to upgrade the performance of lagoons. Most of the effort has been directed toward algae removal techniques, which in turn would contribute to improvement in most other effluent parameters. Most of the research has been financed by the Federal Government through the EPA.

60. To be useful to the Corps for upgrading recreation area lagoons, an algae removal scheme would have to be not only effective but also relatively inexpensive, operationally simple, and maintenance free. It should complement these same qualities found in the lagoon system.

Less effective algal removal techniques

61. Several of the techniques investigated have turned out not to be sufficiently effective in removing algae to warrant consideration for use. They include:

a. Direct filtration of lagoon effluents with rapid sand filters or multimedia filters. Removal has been generally less than 50 percent unless filtration is preceded by chemical coagulation-clarification.[13]

b. Microstraining. Commercially available strainers have openings too large (20 μ) to trap the desirable algae forms such as *Chlorella* and *Scendesumus*. Experimental work with ultrafiltration using membranes is more promising but has yet to be demonstrated on a practical scale.[13]

c. Series ponds with natural sedimentation in ponds. Long theorized to be effective, this scheme alone simply has not been demonstrated to consistently reduce algal concentrations in the final effluent. Live algal cells, particularly those of the desirable green algae, will not settle where any turbulence is present. Those cells that die and do settle release their nutrients allowing the growth of new cells.

d. Series ponds with chlorination. Chlorination used (usually prior to final cell) to kill algae and promote

settling does achieve a reduction in effluent solids but causes lysing of the algal cells and a release of nutrients that can double or triple the BOD, nitrogen, and phosphorus concentrations in the effluent.[13,17]

e. Submerged rock filters. Research by O'Brien at the University of Kansas[19] produced inconclusive results, but it appears that consistent SS removal cannot be achieved.

Effective algal
removal techniques

62. Several methods for reducing algal concentrations in lagoon effluents appear, from published reports, to be effective or have the potential to be effective in producing effluents which meet or exceed the 30 mg/ℓ standard for BOD and SS. Some would appear to be more desirable than others for use at Corps recreation areas, though direct comparisons are difficult. The relatively effective techniques are discussed in the following paragraphs.

63. Centrifugation. Though capable of 90 percent algal solids removal, this process is very expensive with power costs alone running as high as $120 per million gallons.[13] The only practicable way this process could be used at Corps areas would be as a travelling unit which could move into successive lagoon sites and batch-treat the stored contents of each lagoon.

64. Chemical coagulation-flocculation-sedimentation/flotation. These are standard processes which have been proven to be capable of better than 90 percent removal of algal solids.[13] Units of a capacity commensurate with Corps lagoons are available, but operational costs are high. A 0.5-mgd facility constructed in Lancaster, California, at a cost of $243,000 had an average operation and maintenance cost of $304/million gallons in 1973/74.[13] A smaller scale unit practical for Corps use would probably have higher unit O and M costs. The logical method of use for Corps recreation areas would again be to provide a trailer-mounted unit which travels from site to site and batch processes the entire stored contents of each lagoon.

65. Intermittent sand filters. Full-scale evaluation of intermittent sand filters has been conducted by Reynolds et al.[19,20] at Utah State University. Results show that for hydraulic loading rates varying

from 0.2 to 1.2 million gallons per acre (of filter surface) per day (mgad) the filters reduced total SS from an average of 26.1 mg/ℓ to less than 7.2 mg/ℓ and BOD_5 from an influent average of 8.1 mg/ℓ to an effluent average varying from 1.7 mg/ℓ for a hydraulic loading of 0.4 mgad to 4.3 mg/ℓ for a hydraulic loading of 1.2 mgad. Ammonia nitrogen was reduced from an influent average of 2.469 mg/ℓ to an effluent average for all loading rates of 0.541 mg/ℓ. Length of filter run (before cleaning of filter surface) varied from 14 days with a hydraulic loading of 1.2 mgad to 42 days with a hydraulic loading of 0.4 mgad.

66. The high-quality effluent produced by the intermittent sand filters is impressive, but one must realize that the filter influents (lagoon effluents) in this study already bettered the 30/30 secondary treatment standards. Nevertheless, percent removals are excellent and it appears that intermittent sand filtration is probably the most cost-effective and operationally simple add-on polishing device of those investigated. The Utah State researchers report construction and operating costs per million gallons of filtered effluent vary from $26 to $145. These figures apparently do not include the cost of manually cleaning the filter bed surfaces, a cost which would be significant.

67. Controlled discharge/phase isolation. The controlled discharge method, with several variants, is not a polishing device but rather is an operational technique whereby influent is stored in the lagoon for long periods (usually 6 months) and effluent is deliberately discharged only at specific times when presumably the lagoon contents are of optimum quality and receiving streamflows are high. Studies in Michigan and other Great Lakes States[13-15] show an average effluent BOD_5 of about 15 mg/ℓ and SS of about 30 mg/ℓ. Higher quality effluents are achieved during fall discharge than spring discharge. Also, better effluent is achieved when the discharging cell is isolated for several days or weeks before discharge occurs, that is, the cell must stop receiving influent for this period of time.

68. This latter technique, called phase isolation, has been practiced year round in Woodland, California, where flexible series-parallel operation allows at least one cell to be isolated, preparing to

discharge, at all times. Municipal engineers in Woodland report effluents with BOD_5 and SS well below 30 mg/ℓ at all times.[21]

69. Controlled discharge and phase isolation, the Woodland, California, case excepted, have only been practiced in cold winter areas and with ponds designed at 20 lb BOD/acre/day or less and with at least 180-day storage capacity.

70. Phase isolation has not been studied at all under controlled experimental conditions, although the EPA is currently planning two-phase isolation investigations.

71. Corps lagoons would seem to lend themselves to a type of controlled discharge-phase isolation whereby all the flow during the recreation season is stored without discharge. The lagoon would then go into an isolation phase followed by discharge during late fall or early spring before the new season begins. This is currently the mode of operation for a few lagoons in the Missouri River Division, though little monitoring is done. The technique should be considered for experimental study, particularly for mild winter areas where it has never been attempted, much less studied.

72. Coagulation-sedimentation. In-pond chemical coagulation-sedimentation prior to controlled discharge is a technique which could have useful application to Corps lagoons. Limited experience in Ontario, Canada,[22] with seasonal retention lagoons similar to those at Corps recreation areas has shown suspended solids concentrations of less than 10 mg/ℓ 24 to 48 hr after alum was spread on the pond surface from a motorboat. Mixing and stirring for floc development was done with the outboard motor. Phosphorus precipitation occurs simultaneously with algae sedimentation. Labor requirements were found to be 2 to 3 man-hours per acre and sludge buildup was less than 0.1 in. per application. With further study, particularly for mild winter areas, this technique could prove to be a simple and inexpensive means of ensuring high-quality effluents from controlled discharge Corps lagoons.

73. Land treatment. In addition to the methods just described, a further possibility for the treatment/disposal of lagoon effluents is some form of land treatment. Spray irrigation and rapid infiltration-

percolation, applicable in somewhat permeable and highly porous soils, respectively, are two effluent disposal methods which can completely eliminate discharge to surface waters and the accompanying problem of meeting NPDES permit requirements. The overland flow technique, which is best used with clays and other nearly impermeable soils, generally will produce a runoff which must be discharged, although the runoff will presumably have undergone significant nutrient and SS removal during the land treatment. Overland flow is still in the development stage, and reliable design and performance parameters have yet to be adequately demonstrated for field operations.

74. Spray irrigation, on the other hand, is a full-scale operational reality at several Corps recreation areas, among them: Deer Creek (Huntington District), Arkabutla (Vicksburg District), John H. Kerr (Wilmington District), and Fern Ridge (Portland District). The feasibility of providing land treatment/disposal at other locations and knowing the appropriate type of system needed are very site specific. Under favorable circumstances, however, land treatment/disposal systems may be competitive with intermittent sand filters and may have the additional advantage of ensuring zero discharge.

PART IV: ASSESSMENT OF CORPS LAGOONS

Field Visit Results

75. Over 200 lagoon systems of various types are presently in operation at Corps reservoirs throughout the continental United States, treating sewage from visitors centers, overlooks, picnic grounds, camping areas, and boat ramps, as well as from project administration buildings, powerhouses, and Corps employee residences. Additionally, more than a dozen are in various stages of design or construction. A majority of these lagoon systems are operated by the Corps; the remainder, although built by the Corps, have been turned over to State or local authorities for operation.

76. During October, November, and December 1976, each of eight Corps Divisions with operating sewage lagoons was visited. A total of 53 operating lagoons at 23 reservoir projects were inspected. At each site informal, but generally detailed, interviews were conducted with the project managers, maintenance chiefs, and rangers who live with and operate the lagoons and other treatment systems throughout the year. Division, and usually District, representatives were present during all site visits. In addition to personal notes and color slides taken at each site, all available written information on design, operation, and performance was collected. Additional data on lagoons within Districts not visited were collected by mail and telephone.

77. The distribution of Corps lagoons along with their principal design and operating characteristics are given, broken down by Division, in Tables 2-6.

78. Appendix A contains a summary of each field visit and gives a detailed assessment of the lagoon situation in each Division.

Discussion

Distribution of lagoons

79. Table 2 shows that of the 215 Corps Civil Works lagoons in

the country 186 of them are within the five Divisions which lie generally west of the Mississippi River. Conversely, only 29 are found east of the Mississippi; the New England and North Atlantic Divisions have no lagoon systems at all. Two principal reasons are offered: (1) in the five western and midwestern Corps Divisions (North Central, Missouri River, Southwestern, North Pacific, and South Pacific) the climate and terrain are generally more suitable for lagoons, particularly, zero discharge lagoons; and (2) lagoons are a more accepted form of treatment in these areas than in the east and south--accepted by State agencies, municipalities, and people in general.[1] There are exceptions to this proposition, but the trend is indisputable.

Types of lagoons

80. Lagoons can be classified and compared in many ways. In this study, one of the most significant distinguishing features is the method of final effluent disposal, given in Table 6. One hundred sixty-three or 76 percent of Corps recreation area lagoons are total retention lagoons with no discharge. This is no accident; if the climate and land availability will allow this type of design, discharge and permit problems are immediately solved.

81. The fact that recreation area lagoons receive influent only about half the year works in favor of total retention ponds. Theoretically, a pond can be designed for total retention in any location where annual lake evaporation exceeds precipitation, as long as enough storage volume and surface area are provided, but to contain year-round flows such a pond would have to be prohibitively large. Seasonal flow (of about 6 months), on the other hand, can be contained with much smaller volume, and the required surface area can be cut down tremendously. Moreover, total retention ponds for seasonal flows can be provided in marginal areas, such as eastern Kansas, Iowa, Missouri, and Nebraska, where they otherwise would not be feasible.

82. A possible long-range problem with these evaporative ponds is the gradual buildup of dissolved salt to levels toxic to algae, although there are ponds in the Tulsa District as old as 10 years that have yet to show any signs of this problem.

83. Of the remaining 52 lagoons which do discharge an effluent, 14 apply their effluent to the land and 15 practice the controlled discharge technique (even the latter are total retention ponds most years). Only 23 Corps lagoons, then, discharge to surface waters more or less continuously during the recreation season. Twenty-one of these 23 are polishing ponds following package activated sludge plants in the eastern Corps Divisions (Ohio River, South Atlantic, Lower Mississippi Valley, New England, and North Atlantic).

84. It is felt that the seasonal retention (controlled discharge) method (15 ponds in the Missouri River Division) has tremendous potential, not only for the Great Lakes area where it is standard but for the warm and/or humid areas of the eastern Divisions where it simply has not been tried, where lagoons have heretofore had a generally bad name, and where package plants presently contribute to great expense and problems.

85. Spray irrigation is a land treatment process, gaining in popularity throughout the Corps, which generally avoids all discharge to surface waters and thereby solves the NPDES permit problem in an environmentally sound way. Though still considered to be in the experimental or demonstration stage in most circles, spray irrigation is a full-scale operational reality in several Districts. Land treatment appears to have a bright future at recreation areas and to be an attractive alternative for the disposal of lagoon effluent.

86. Polishing ponds following activated sludge package plants, of which there are 23 at Corps recreation areas, have been notably ineffective in accomplishing anything except growing algae. Originally intended to remove nutrients and settle excess SS often present in extended aeration effluent, polishing or tertiary ponds, in the end, accomplish neither. To produce a consistently acceptable effluent a tertiary pond of this sort would have to be followed by or incorporate one of the algae removal techniques discussed previously. In the latter case, the package plant would be essentially superfluous. As these systems presently exist, however, the ponds degrade the package plant effluent through algal growth; the receiving streams would be better off

with the package plant effluent discharged directly. See further discussion of this subject in Appendix A under the Ohio River Division summary.

Problems of underloading

87. The most discernible design problem, which is also to some extent an operational problem, is hydraulic underloading of recreation area lagoons. A corollary beneficial effect of hydraulic underload, which often prevents the low water levels and nearly dry beds from causing great odor problems and which allows even polishing pond effluents to often come reasonably close to permit limitations, is the very light organic load received by the lagoons. No measured data were available, but the author estimates that 90 percent or more of Corps lagoons are actually loaded far below 20 lb BOD/acre/day, the generally accepted minimum design load even for cold climates.

88. The main cause of hydraulic underload is hydraulic overdesign, for which there are two basic reasons: (1) designs are usually based on future or ultimate development of recreation area facilities; and (2) flow estimates from the various facilities--comfort stations, showers, trailer dump stations, etc.,--have been consistently too high.

89. The first problem, design based on future expansion, is nearly unavoidable. Generally, it is more economical in the long run to build treatment facilities now for future flows, unless the future expansion is going to be many multiples of the present condition or the expansion is too far into the future.

90. The second problem, overestimating wastewater production, can be avoided with more realistic methods for flow estimation and wastewater characterization. Corps planners and field personnel are acutely aware of the need for better flow criteria. Such criteria are currently being developed by WES.

91. Alleviating the effects of hydraulic underload at existing lagoons is something which needs more immediate attention. Though very few odor problems due to low water levels or dried up lagoons were reported to the author by field personnel, it is felt that more exist than are reported; furthermore, as the lagoons become older and bottom

sludge layers begin to develop more fully, odors will be more likely to occur during low water levels, particularly in the spring. The solution is to keep lagoon depths at a minimum of 2 to 3 ft. This can either be done by adding supplementary water as necessary or by subdividing underloaded cells with internal dikes. Both these steps have been taken, on local initiative, at a few Corps lagoons around the country, but many more need such measures.

92. A supplementary water source should be routinely provided at any waste treatment facility, lagoons included, and though many Corps lagoons do not have it now, consideration should be given for providing the supplementary water source in the future.

Number of cells

93. Table 3 shows the breakdown of single-cell Corps lagoons versus multiple-celled lagoons. In many cases a single cell is adequate; for example, an evaporation pond following a septic tank in the South Pacific Division does not need multiple cells, though two cells would permit better depth control as discussed above. Generally, however, a minimum of two cells arranged for parallel or series operation is the goal. Most newer Corps lagoons meet this standard, even those which are total retention ponds. It has been pointed out by Parker[13] that three or more cells in a series do not provide any greater BOD or SS reduction than two cells. In the Corps' case two cells should be adequate for most systems, especially those with total retention. For those systems at which a phase isolation operation is anticipated, a three-cell system (one primary cell in series with two parallel secondary cells) would be ideal, although with only 6 months of loading, phase isolation could be practiced with two or even one cell. Having many cells in series has the one certain advantage of guaranteeing long detention times and consequent coliform die-off. Additional cells may also be appropriate for ensuring adequate depth under present hydraulic loads while also providing for future increased loads.

Maintenance

94. The appearance of Corps lagoons nationwide is generally excellent, with a few isolated exceptions. Major maintenance problems

encountered on the field visits in descending order of frequency observed were: emergent and shoreline weeds (cattails mostly); duckweed; cracked, torn, or leaking liners; burrowing rodents in dikes causing deterioration and ruining water retention ability; wave erosion of inner slopes; and willow and cottonwood growth along banks.

Liners

95. Most Corps lagoons have either membrane-type liners, a bentonite liner, or a nearly impermeable compacted layer of natural clay subsoil. One lagoon in the North Pacific Division is completely lined with asphalt. Natural sealing by sludge deposits usually takes place over a period of years regardless of the type of bottom, although this should not be relied upon to ensure sealed lagoons.

96. In the Missouri River Division, Southwestern Division, and elsewhere where natural subsoil is the only liner used, seepage is assumed and taken into account in the design.

97. State pollution control agencies are becoming increasingly strict on groundwater contamination; some are beginning to insist on complete impermeability in ponds and lagoons of all kinds. In anticipation of the day when this will be true nationwide, the Corps should consider providing impermeable linings on all future lagoons.

Acceptance and success

98. Where lagoons are the only form of treatment at a Corps project they are accepted by project personnel for what they are and are considered to be a good method for waste treatment/disposal. Though not appreciated by maintenance and ranger personnel, as no sewage facility ever is, they are well tolerated. At projects which have a mix of package plants and lagoons, lagoons are far and above preferred by project personnel. They are perceived to require less operational and maintenance time and money and do a better job. At projects that have no lagoons but use only package plants and/or septic tanks, lagoons are poorly understood and thought to be a foul and primitive solution.

99. In summary, lagoons in many forms are providing adequate or better sewage treatment/disposal at over 50 Corps projects. They are convenient, inexpensive, and generally well liked. Due to the extreme

variability of the wastewater flows, lagoons are more promising and have a better chance of consistent, successful operation at recreation areas than mechanical plants. Moreover, lagoons that are loaded for only 6 months of the year have a better chance for success through greater operational flexibility than do lagoons loaded year round.

PART V: CONCLUSIONS

100. The conclusions given below take into account and attempt to synthesize both the present published state of the art and the present lagoon situation at Corps recreation areas. Any general conclusions regarding a subject as variable as sewage lagoons must be tempered with good engineering judgment and knowledge of the specific local situation.

a. Facultative lagoons are well suited to perform the principal wastewater treatment role at most seasonal Corps recreation areas.

b. Mechanical aeration may effectively supplement photosynthesis as an oxygen source in a lagoon and can be used to upgrade the capacity of an organically overloaded lagoon or minimize the required surface area in a new lagoon.

c. Anaerobic lagoons (septic tanks excepted) do not have a useful role at recreation areas.

d. Total retention lagoons have been an effective, inexpensive, and relatively trouble free means of preventing the discharge of any pollutants into surface waters at many Corps projects in areas where annual evaporation exceeds precipitation.

e. Controlled discharge has been shown to be capable of producing acceptable effluents (1977 standards) in northern areas but needs to be studied in warmer, more humid areas for effectiveness.

f. Phase isolation, a promising variant of controlled discharge, has not been scientifically studied anywhere to date and has not yet been demonstrated in the south and east.

g. In-pond chemical coagulation-sedimentation prior to controlled discharge needs to be studied for effectiveness in warmer, more humid areas.

h. Algal solids can be effectively removed from lagoon effluents by any of several processes. They are listed below, in probable order of most feasible to least feasible, in terms of cost and simplicity of operation and maintenance:

   (1) Intermittent sand filtration.

   (2) Chemical coagulation-flocculation-sedimentation/flotation (travelling batch processor).

(3) Centrifugation (travelling batch processor).

i. Land treatment without runoff (irrigation, percolation) is an effective means of preventing discharge of pollutant-carrying lagoon effluents into surface waters.

j. The traditional maximum allowable depth of 5 to 6 ft for facultative ponds is without foundation and should be abandoned. Deeper facultative ponds need to be studied for various effects as discussed herein.

k. Most Corps lagoons are operating at hydraulic and organic loads far below design.

l. Lagoons are ineffective as polishing devices for the tertiary treatment of activated sludge effluents.

PART VI: RECOMMENDATIONS

101. This part is divided into two sections. The first section contains recommendations that can be used where applicable by personnel involved in planning, design, or operation of wastewater treatment facilities at Civil Works projects. They are intended to improve the effectiveness and eliminate or mitigate problems of lagoons in particular and wastewater treatment in general.

102. The second section recommends four specific and one general area of lagoon research, the accomplishment of which would enhance the performance and potential of lagoons at Corps projects. The recommended research has a primary objective of developing techniques to improve and demonstrate the potential of lagoon treatment in the East, Southeast, deep South, and eastern Midwest where lagoons have not had widespread acceptance but where the Corps has many heavily used recreation areas.

Recommended actions

103. The following steps are recommended for Corps personnel involved with wastewater treatment facilities:

- a. Seriously consider the lagoon as an alternative for each future recreation area waste treatment facility.
- b. Avoid, where at all possible, lagoon designs with uncontrolled discharge of effluent to streams or lakes by using one of the following schemes: total retention; seasonal retention/controlled discharge; or land treatment.
- c. Where more or less continuous discharge is unavoidable, consider intermittent sand filters as an effective algae removal and polishing process at a comparatively low cost.
- d. Provide a supplementary source of water at all existing and future lagoons for maintaining adequate depths in hydraulically underloaded lagoons and for general sanitation.
- e. Consider subdividing existing underloaded lagoons with internal dikes as a means of maintaining proper depths.
- f. Design lagoons with a minimum of two cells with influent, effluent, and intercell piping that allows parallel operation or series operation in either direction.
- g. Design effluent structures that permit subsurface withdrawal at various depths.

h. In the future, do not construct polishing ponds that follow extended aeration activated sludge or other secondary treatment schemes, and give consideration to bypassing existing such ponds.

Recommended research

104. The following research is recommended:

a. Studies to determine the effectiveness and feasibility of the phase isolation/controlled discharge technique for seasonally loaded lagoons in a humid, mild-winter climate.

b. Studies to evaluate the effectiveness of in-pond chemical coagulation-sedimentation for algae removal prior to controlled discharge for lagoons in humid, mild-winter areas.

c. Pilot scale experiments with deep, facultative lagoons, including studies of: performance; vertical distribution of algal solids, DO, pH, etc; and various multilevel withdrawal techniques and devices.

d. Studies comparing the effect of various types of inlet and outlet structures on lagoon performance.

e. Additional research in support of stated objectives for which a need may become apparent in the course of this work unit; for example, a project to demonstrate the feasibility of a travelling batch processing plant to remove algae from lagoons discharging under controlled conditions.

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Table 1

Relative Ability of Facultative Lagoons to Remove Pollutants

Constituent	Rating*	Remarks
Suspended solids	4	Seldom meets 30-mg/ℓ standard
BOD_5 unfiltered	2-3	Unfiltered: occasionally meets 30-mg/ℓ standard
BOD_5 filtered	1-2	Filtered: usually less than 10 mg/ℓ
Coliform bacteria	1	+99% coliform removal (fecal and total) with actual detention time of +30 days in system
Total nitrogen unfiltered	3-4	Proportion of these nutrients contained in algal cells and in solution is highly dependent on influent concentrations, pH, and other factors
Total nitrogen filtered	2-3	
Total phosphorus unfiltered	3-4	
Total phosphorus filtered	2-3	

* 1 = excellent; 2 = good; 3 = fair; and 4 = poor.

Table 2

Number of Lagoons at Civil Works Projects

	Corps Division										
	Lower Miss. Valley	Missouri River	New England	North Atlantic	North Central	North Pacific	Ohio River	South Atlantic	South Pacific	South-western	Total
Lagoons at Civil Works projects	7*	53	0	0	10	10	19	3	8*	105	215

* Additional lagoons in various stages of construction.

Table 3

Number of Cells Found in Corps Lagoon Systems

	Corps Division										
	Lower Miss. Valley	Missouri River	New England	North Atlantic	North Central	North Pacific	Ohio River	South Atlantic	South Pacific	South-western	Total
Number of one-cell systems	3	3	NA	NA	0	3	18	2	7	45	81
Number of systems with two or more cells	4	50	NA	NA	10	7	1	1	1	60	134

Table 4

Number of Aerated and Facultative Lagoon Systems

	Corps Division										
	Lower Miss. Valley	Missouri River	New England	North Atlantic	North Central	North Pacific	Ohio River	South Atlantic	South Pacific	South-western	Total
One or more aerated cells	3	0	NA	NA	0	6	2	1	0	5	17
Complete facultative systems	4	53	NA	NA	10	4	17	2	8	100	198

Table 5

Position in Treatment Process Chain

	Corps Division										
	Lower Miss. Valley	Missouri River	New England	North Atlantic	North Central	North Pacific	Ohio River	South Atlantic	South Pacific	South-western	Total
Lagoons receiving raw sewage	6	53	NA	NA	10	10	1	1	1	5	87
Lagoons following septic tank	0	0	NA	NA	0	0	0	0	8	98	106
Polishing ponds following activated sludge	1	0	NA	NA	0	0	18	2	0	2	23

Table 6

Method of Final Effluent Disposal

	Corps Division										
	Lower Miss. Valley	Missouri River	New England	North Atlantic	North Central	North Pacific	Ohio River	South Atlantic	South Pacific	South-western	Total
Discharge into river or lake	1	15*	NA	NA	0	0	18	2	0	2	38
Spray irrigation	4	0	NA	NA	0	5	1	1	0	--	11
Other land disposal	0	0	NA	NA	0	3**	0	0	0	--	3
Total retention (no effluent)	2	38	NA	NA	10	2	0	0	8	103	163

* These are controlled discharges into intermittent streambeds or open land; ultimate drainage may reach lake if effluent volume is sufficient or wet weather activates intermittent streams.

** These other land disposal methods are: drainfield (1), percolation pond (1), and deep percolation well (1).

APPENDIX A: INDIVIDUAL FIELD VISIT SUMMARIES

Lower Mississippi Valley Division

1. There are only four Corps-operated lagoons and three Corps-built, State-operated lagoons in the Lower Mississippi Valley Division (LMVD). In addition one aerated two-cell system is under construction.

2. Two systems are presently zero discharge types operating through a combination of evaporation and seepage. At Lake-o-the-Pines, Texas, where the current system consists of a single cell treating diluted vault waste, the plan is to bring new waterborne comfort stations on line, add a second cell, and convert from a total retention mode to a land treatment system. An underloaded two-cell lagoon followed by land treatment is in operation at Arkabutla Lake, Mississippi. No National Pollutant Discharge Elimination System (NPDES) permit is required because there is no discharge to surface waters. The only lagoon with a discharge permit is a polishing pond following a package activated sludge treatment plant at Kaskaskia Lock and Dam, Illinois. It seldom meets the very strict NPDES permit limitations (biochemical oxygen demand (BOD), 4 mg/ℓ; suspended solids (SS), 5 mg/ℓ), and, as a result, plans are being made to use the effluent for lawn and garden irrigation at the project. Polishing ponds are discussed in detail in the main text and in the Ohio River Division discussion of this appendix.

3. The three State-operated systems are all in Illinois and use a diffused air system followed by land treatment.

Missouri River Division

4. Lagoons are widely and successfully used at Corps projects in the Missouri River Division (MRD). They are not only the most common method of sewage treatment and disposal but are clearly the preferred method by all concerned, from the sanitary design people to the park rangers. In all there are 53 Corps-operated lagoons in MRD with 45 in the Kansas City District and 8 in the Omaha District. The typical

lagoon in MRD is a two-cell facultative system that receives raw wastes. In the semiarid climate of the plains and prairies of MRD most of the lagoons are deliberately designed for complete year-round detention by matching precipitation plus design inflow to evaporation plus seepage and checking surface BOD loading against State criteria; the latter never governs in surface area determination. About 15 of the lagoons are designed for 180-day retention and annual controlled discharge, but because design hydraulic loads have not been realized, even these rarely discharge. Twelve ponds, six at Rathbun Reservoir and six at Perry Reservoir, both in the Kansas City District, did discharge in February 1974 under controlled conditions. The Environmental Protection Agency (EPA) monitoring data showed both BOD and SS well below 30 mg/ℓ and, with one exception, fecal coliforms well below 200 per 100 mℓ. For most ponds the discharge outfall was into a dry gully or open field where it is doubtful that any effluents would ever reach surface waters except during very wet weather.

5. The flexibility and versatility of inlet, outlet, and interconnecting pipes and structures ranged from excellent at some sites to inadequate at others.

6. Vault wastes are frequently disposed of into lagoons with no apparent adverse effects.

7. Most lagoons in MRD are unlined due to a natural clay subsoil; some seepage (about 1/8 in. per day) is usually considered in the designs. The most significant problem is the hydraulic underloading of lagoons, often to the point of totally dry lagoon beds. The apparent reason is that the lagoons were designed for ultimate future development of recreational facilities and for heavier user wastewater productic than in fact occurs. Despite low water levels and dry lagoons, on-site personnel in MRD report surprisingly few odor problems.

8. Emergent and shoreline weeds are a constant problem, which each project handles in its own way with greater or lesser zeal. Physical removal, herbicides, and soil sterilants all have been used successfully in MRD. Dike maintenance is generally good, although burrowing rodents and beavers are doing damage at some sites.

9. At Perry Reservoir, Kansas, chain link fences were on top of the dikes, severely impairing truck access and maneuverability.

North Central Division

10. There are 10 Corps-operated lagoons in North Central Division (NCD), all in the Rock Island and St. Paul Districts. All are facultative, raw sewage lagoons, with two or more cells and are designed for complete retention-evaporation of all flows. Vault wastes are routinely added to lagoons. Inlet and intercell pipes and structures provided series-parallel flexibility. No outlet or overflow pipes are installed in NCD lagoons, apparently showing great confidence in the zero discharge designs. It was brought out during the visit that if, in an emergency, overflow were imminent, the lagoons would be pumped out and the effluent used for irrigation.

11. No NPDES permits have been issued for NCD's zero discharge lagoons and no operating problems have been experienced to date, although all the lagoons are less than 3 years old. As in MRD, hydraulic loads are far below design, resulting in some totally dry cells.

12. The chief maintenance problem has been weed control.

North Pacific Division

13. There are 10 lagoon systems in the North Pacific Division (NPD), not counting 14 aerated lagoons at military bases in Alaska. Of these ten, nine are seasonally loaded recreation area ponds and one serves the town of Rexford, Montana, relocated by the construction of Libby Dam.

14. The emphasis in NPD is on engineering to avoid discharge into surface waters. Where the climate permits (east of the Cascades) lagoons are designed for complete retention (two systems); where this is not possible, effluents are disposed of by land treatment in some form, either spray irrigation (five systems), drainfield (one system), percolation wells (one system), or percolation ponds (one system). All effluents applied to the land in any form are first chlorinated.

15. There are three single-cell systems and seven two- or three-cell systems. Four systems are facultative while six have mechanical aeration in the first cell. All but one of the systems are lined; liners used include clay, polyvinyl chloride (PVC), and asphalt.

16. All the lagoons are currently operating well below design load, but at most sites provisions are made to keep the water levels at a minimum of 3 ft by adding supplementary water as necessary.

17. No significant operational problems were reported within NPD. Duckweed growth was the biggest maintenance problem observed.

Ohio River Division

18. With the exception of Deer Creek Reservoir whose facultative lagoon handles raw sewage, all the lagoons in the Ohio River Division (ORD) are so-called polishing ponds following package extended aeration plants. The original reason for having a lagoon following a sophisticated secondary treatment unit was nutrient (nitrogen, phosphorus) removal by algae and/or supplemental clarification by sedimentation. It has been pointed out with increasing frequency in the literature (and the lagoons in ORD are prime examples) that polishing or tertiary ponds with detention times long enough to grow algae succeed only in increasing final effluent SS as algae. Some nitrogen and phosphorus is taken up by algal growth, but it is then discharged in organic form with the algae. Verbal reports from project personnel in the Louisville and Nashville Districts bear this out. The only data available which shows pond influent and effluent SS are those from a sample taken at Mississinewa Reservoir, Indiana (Louisville District). It showed pond influent (package plant effluent) SS at 12 mg/ℓ and pond effluent SS of 73 mg/ℓ.

19. Two further detrimental effects of polishing ponds, both reported at the Upper Wabash Reservoirs in Indiana, are: high pH readings (over 9.0) due to algae growth and difficulty in establishing required 0.5-mg/ℓ chlorine residuals due to the chlorine demand exerted by algae. Recognizing these problems, operations personnel in the Huntington District have recently eliminated a polishing lagoon from the treatment train at one site.

20. Despite the undesirability of lagoons as tertiary devices, the few discharge monitoring reports available show that permit standards are being met over 80 percent of the time for BOD, SS, fecal coliforms, and pH. This could be partially attributed to the fact that the treatment systems are extremely underloaded organically, and there simply is not enough pollutant coming into the system to result in a pollutant-laden effluent. Any discharges at all, of course, are rare, occurring generally only during summer weekends.

21. Other problems reported by field personnel in ORD include duckweed and torn and floating PVC liners.

South Atlantic Division

22. The South Atlantic Division (SAD) recreation areas combine very heavy use with relatively undeveloped waterborne sanitary facilities. Only three lagoons are found in the Division: an aerated-facultative lagoon system at John H. Kerr Reservoir (Wilmington District), which treats raw sewage and features spray irrigation disposal; and two polishing ponds following package plants in Mobile District, one of which is State-operated on State land.

23. There was no operational or performance data available on the two polishing ponds and very little information was available from State or Corps project personnel. Each of the package plant-lagoon systems served one public shower/latrine building and was badly underloaded. It was apparent that the package plants were unpopular, both with State personnel at Alatoona Lake, Georgia, and Corps rangers who had responsibility for the unit at Miller's Ferry Lock and Dam, Alabama.

24. The system at John H. Kerr Reservoir (Wilmington District) receives a lot of attention as it is a spray irrigation demonstration project. However, since there is no discharge and no NPDES permit, there is no lagoon performance monitoring done other than dissolved oxygen, pH, and settleable solids. This aerated-followed-by-facultative system was designed for 15,900 gpd and 44 lb BOD/day (about 83 lb/acre/day) including diluted pit privy waste. During the first year this

lagoon appears from available records to have been handling about half its design hydraulic load.

25. SAD is a region where the Corps has little lagoon experience, but is also a great opportunity for adding to and upgrading sanitary and waste treatment facilities at the many recreation sites. Lagoon performance under seasonal loading should be further studied for the conditions found here.

South Pacific Division

26. There are eight operating lagoons and six under construction at eight recreation areas in the South Pacific Division (SPD). All are within the Sacramento District and located at the flood control/irrigation reservoirs in the arid Sierra Nevada foothills in central California. There are also numerous lagoons treating year-round flows at small military installations throughout Southern California, Arizona, Nevada, and Utah, but these will not be discussed here.

27. All lagoons in SPD follow septic tank treatment and are designed for complete retention/evaporation of sewage flows plus precipitation. Except for one lagoon at Lake Isabella, none have an emergency overflow pipe. Monitoring data and permit requirements are irrelevant and nonexistent.

28. With one exception, the six ponds inspected were lined with polyethylene sheeting; in several cases the covering soil layer had been washed away, leaving the liner exposed to the sun and riddled with cracks and holes. The lagoons in this region are generally built on high ground away from public use areas. The practice helps keep the public away from the ponds and potential odors away from the public but also necessitates extensive pumping of septic tank effluent.

29. Odor production was reported to occur occasionally during the beginning of the recreation season in the spring when lagoon levels are generally low. Extensive cattail growth and dike infestation by rodents are major problems in SPD that are not currently getting the attention they should. The cattails in one lagoon were cutting the effective

surface area for evaporation in half and significantly reducing the pond volume.

30. Four of the six ponds observed were dry or nearly dry. A contributing factor is the two successive very dry years experienced in the area, but the principal reason is that design flows are not being experienced. This stems from: inability to accurately estimate wastewater production based on facility usage, as yet incomplete development of public use facilities for which lagoons were planned, and increasing use of low-flow toilets in this water-scarce region. The problem is severe enough that the second cell of the two systems inspected had never received any wastewater, even during wet years.

31. Despite a few problems, SPD personnel seem generally pleased with their septic tank-pond systems with zero discharge.

Southwestern Division

32. Of the 105 lagoon systems in the Southwestern Division (SWD), 96 are operated by the Tulsa District, 7 by the Fort Worth District, and 2 by the Little Rock District.

33. In the Tulsa District, the ponds range in size from 12 by 12 ft to 200 by 200 ft and in number of cells from one to four. Thirty of these ponds have man-made liners, four are mechanically aerated, and only one has an NPDES permit. All of these lagoon systems follow septic tanks which settle and digest solids and reduce the organic load to the ponds by 40 percent or more. In addition to waterborne sewage, most of these lagoons received trucked vault wastes; concrete ramps facilitate the sanitary dumping of vault wastes, an innovation that could be emulated elsewhere. Inlet structures and intercell piping in the newer lagoons provide for series or parallel operation, whereas in some of the older lagoons the arrangement requires complete filling of the primary cell before any water overflows into the secondary cell. All of the Tulsa District's lagoons are of the total retention type. Typical problems include hydraulic underload, dry cells, and weed control.

34. All of the Fort Worth District's lagoons are totally retentive;

two follow septic tanks, two follow package plants, and two receive diluted vault wastes only.

35. In the Little Rock District a two-cell facultative system at Table Rock Lake, Missouri, discharges in the 500- to 1000-gpd range (design flow 4000 gpd) during the recreation season and does not regularly meet its NPDES permit standard of 20 mg/ℓ BOD and SS. It is to be replaced by a septic tank-surface sand filter system. The three-cell aerated system at Norfork Lake, Arkansas, seldom discharges, but on the random occasions when it does, it greatly exceeds its 1 July 1977 limitation of 10 mg/ℓ BOD and 15 mg/ℓ SS. The current plan here is to pump effluent for flower garden irrigation rather than discharge.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Hand, Terry D

The role of sewage lagoons at Corps of Engineers recreation areas / by Terry D. Hand, Randall R. Williams. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1977.

42, [4], 8 p. : ill. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; Y-77-5)

Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C.

References: p. 37-42.

1. Lagoons (Ponds). 2. Recreational areas. 3. Sewage treatment. 4. United States. Army. Corps of Engineers. 5. Waste treatment. I. Williams, Randall R., joint author. II. United States. Army. Corps of Engineers. III. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; Y-77-5.

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